ENGINEERING CONTROL OF HEALTH AND SAFETY HAZARDS IN URANIUM MINES

By James Westfield, R. H. Flinn, A. D. Look, and G. G. Morgis

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by

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SUMMARY AND INTRODUCTION

Uranium activity has introduced a comparatively new hazard to United States mining. In addition to the hazards common to all mines, uranium mines have a complex health problem of radiation damage. Like many new processes, radiation and nuclear energy can be made to serve man in many useful ways when properly understood and handled; but, like fire, gases, and electricity, their potential dangers must be known and respected, and appropriate precautions must be taken or death may result.

Since 1950 the Public Health Service has been conducting basic investigations on exposure to radon and its daughter products and the effect of exposure upon the health of miners in uranium mines of the Western States. The Bureau of Mines assisted in several of these investigations, especially in mines on Indian lands. The studies have shown that a serious health hazard exists from radioactive exposure that might cause lung cancer if continued over a number of years. The Public Health Service report, Control of Radon and Daughters in Uranium Mines and Calculations on Biologic Effects,[6/] shows that 55 percent of the uranium mines employing 64 percent of the miners had atmospheric concentrations more than five times the working level now accepted as reasonably safe for industrial exposures. Extensive control measures are necessary to reduce these concentrations to the suggested working level of less than 300 micromicrocuries of total radon daughter products per liter of air.

Now that the basic studies of the Public Health Service have defined the problem and methods of control, the Bureau of Mines is responsible for providing follow-up health and safety services and inspecting mines on Indian lands, as well as those on the Public Domain leased from the Federal Geological Survey, and for offering and making available these services to other mines, particularly those on Government

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lands having leases from the Atomic Energy Commission. Continuous engineering environmental surveys of the actual and anticipated mining operations are necessary to (1) evaluate the radiation, dust, and accident hazards in each mining area; (2) advise on techniques of ventilation and dust control; and (3) determine additional measures that should be taken to protect the health and safety of the workers.

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ORIGIN AND FORMATION OF URANIUM

Tremendous energy is locked in uranium - the same kind of energy that created our universe. We know that all matter is composed of certain basic elements. Many believe that these elements came from the fiery cores of ancient suns several billion years ago.7/ The cycle is thought to have begun with hydrogen, which has the simplest atom of all. Its nucleus contains 1 proton, and whirling around this core in a specified orbit is 1 electron. Within suns, hydrogen atoms are believed to have fused and neutrons joined the nucleus, forming a new element - helium. Its 2 protons attracted 2 electrons. Helium, in turn, became the next heaviest element - lithium - as more particles joined its nucleus. Thus, one by one, many of the elements found in nature today were forged until finally uranium, the heaviest atom of all, was created. It has a nucleus of 92 protons and 146 neutrons, held together by stellar energy, which man has at last learned to control and release for his own use. Scientists discovered that, when a neutron strikes a uranium nucleus, it may be absorbed. Under the strain of the added particle, the nucleus grows unstable and splits in two with a burst of energy, releasing more neutrons. In a mass of uranium, the neutrons released by one fission travel on to produce further fissions, liberating more and more energy in an intense chain reaction.

HISTORICAL REVIEW OF PROPERTIES AND OCCURRENCES OF URANIUM

In addition to the metallic element uranium, uranium ores contain all members of the radioactive series of which uranium is the parent. This list includes radium which decays to radon - a dense radioactive gas. Although uranium never occurs in pure form in nature, it is widely distributed and enters into the composition of several ores. Uranium has an atomic weight of 238.07, a density of 18.7 to 19.08, and a melting point of 1,132° C. ± 1° C.

Usually, uranium has been found in minerals associated with the three major types of rock - igneous, sedimentary, and metamorphic. In igneous rocks uranium deposits occur in hydrothermal veins, disseminated bodies, and pegmatites. In sedimentary rocks uranium-bearing ores occur in sandstone, limestones, shales, and phosphorites, as well as in lacustrine-saline deposits and in alluvial and placer deposits. In metamorphic rocks uranium may occur in quartzites, gneisses, or schists. There are over 150 uranium-bearing materials. Some occur as primary and many others as secondary minerals. Primary minerals have not been altered since their formation by igneous action. Secondary minerals are formed as a result of decomposition of the original primary mineral.

7/ Union Carbide and Carbon Corporation, The Petrified River, The Story of Uranium: Booklet accompanying film produced cooperatively by Union Carbide and Carbon Corporation and the Federal Bureau of Mines, 1956, 24 pp.

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Uraninite or pitchblende is by far the most important primary uranium mineral. It is essentially uranium oxide and is the chief constituent of virtually all high-grade uranium ore. Pitchblende has been the principal source of uranium output in the Belgian Congo, Canada, and Czechoslovakia. No major concentrations were found in the United States until recent years, when it was discovered in flat-lying disseminated deposits on the Colorado Plateau.

Carnotite, which is classed as a secondary uranium mineral, has been commercially important in the United States for many years as a source of vanadium, radium, and uranium. Carnotite ores were discovered on the Colorado Plateau in the Rocky Mountain area between 1881 and 1887, and some mines were developed during this period. As there was little demand for these materials, production was small. Domestic production of radium from carnotite ores was significant from 1916 until 1923; however, in 1923 radium became available from high-grade Belgian Congo ore, and the low-grade American ores were no longer competitive. Thus, until after World War II there was no sustained and large-scale employment in uranium mines.

At present, 1,000 mines, which yield uranium ores of various types, employ more than 5,500 miners and approximately 3,000 millers. The largest production comes from the Colorado Plateau area, which covers more than 100,000 square miles in southeastern Utah, southwestern Colorado, northeastern Arizona, and northwestern New Mexico; however, discoveries and new production continue in other areas.

Measured, indicated, and inferred reserves of uranium ore in the United States have been estimated recently at 76 million tons.

TYPES OF RADIATION

The three units of radiation that predominate in most uranium mines are alpha, beta, and gamma emissions. An alpha particle is identical with the nucleus of a helium atom. Alpha particles have a double positive charge and, because of their comparatively large mass, will not penetrate the skin. Alpha particles can enter the body by inhalation or by ingestion of the radioactive material producing it.

A beta particle has a single negative charge and a mass equal to that of an electron. Essentially, a beta particle is a high-speed electron emitted from a radioactive source; because of its very small size it has greater penetrating ability than an alpha particle. Although primarily an internal hazard, beta radiation produces severe burns if the victim is exposed at short range to an exceptionally beta-active and radioactive surface.

A gamma ray is a short-length electromagnetic wave produced by radioactive decay. It is a photon of energy nearly identical to X-ray. The gamma ray does not possess mass, but it has energy and consequently the power of destroying human tissue. In nuclear explosions the principal immediate danger to health is damage from the gamma rays, but in mining operations most of the danger is damage from alpha and beta particles.

The activity of a radioactive substance usually is measured in curies. A curie is defined as the quantity of radioactive material that emits 2.22×10^{12} atomic disintegrations per minute. Thus, a gram of radium, which is the standard, will emit 2.22×10^{12} alpha particles per minute. This gram of radium may be visualized as a machinegun discharging 37 billion bullets per second.

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A convenient method of defining the activity of an unstable element is to express its radioactive life in terms of the time it takes to lose one-half (50 percent) of its activity by decay. This is known as the half life. At the end of 2 half lives half of the remaining activity will be lost, so 25 percent of the original activity will remain; at the end of 3 half lives, 12.5 percent of the activity will be left; at the end of 4 half lives 6.25 percent of the original activity will remain; and at the end of 5 half lives 3.13 percent of the original radioactivity will be left, hence the radioactivity will be essentially exhausted. The rate of decay of the element and its half life do not depend upon temperature, pressure, chemical combination, or any other ascertainable condition.

Uranium has a half life of 4 1/2 billion years. Radium, a disintegration product of uranium, has a half life of 1,620 years, whereas radon, a gaseous product formed from the disintegration of radium, has a half life of only 3.825 days. Radon is chemically inert and is the heaviest gas known, being seven times as dense as air.

When radon is formed, it immediately starts breaking down into radium A; radium A disintegrates into radium B, radium B into radium C, radium C into radium C', and radium C into radium D. As radium D takes a long time to attain an appropriate fraction of the radon concentration, in all further discussions in this paper the chain following radium C' is ignored. These daughter products of radon are nuclei particles whose half lives are: Ra A - 3 minutes, Ra B - 26.8 minutes, Ra C - 19.7 minutes, Ra C' - 0.0002 second, and Ra D - 22 years.

TABLE 1. - Radioactive transformation of uranium series from radium to radium D

Common name	Isotope	Emission	Half life
Radium	$_{88}Ra^{226}$	Alpha	1,622 years.
Radon	$_{86}Rn^{222}$	do.	3.825 days.
Radium A	$_{84}Po^{218}$	do.	3.05 minutes.
Radium B	$_{82}Pb^{214}$	Beta gamma	26.8 minutes.
Radium C	$_{83}Bi^{214}$	do.	19.7 minutes.
Radium C'	$_{84}Po^{214}$	Alpha	164×10^{-6} seconds.
Radium D	$_{82}Pb^{210}$	Beta gamma	22 years.

OCCUPATIONAL HAZARDS OF URANIUM MINING

Air impurities in uranium mines include radioactive dust and gas, gas and smoke from blasting, dust from mining operations, and exhaust gases when diesel-operated equipment is used. These impurities may be irritating, toxic, or both. The principal harmful gases comprising the exhaust from diesel-powered equipment are carbon dioxide, oxides of nitrogen, oxides of sulfur, carbon monoxide, and aldehydes.

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As a result of many years of laboratory and underground work on diesel exhaust gases, the Bureau of Mines in 1949 issued a schedule for permissibility and suitability tests covering Procedure for Testing Mobile Diesel Powered Equipment for Non-coal Mines and included recommendations for the use of diesels underground. This schedule (No. 24) was revised in April 1955, and to date the Bureau of Mines has granted 14 approvals. It is strongly recommended that only diesel equipment approved by the Bureau of Mines be used underground.

Although it is recognized that the oxides of uranium and the metals such as lead, nickel, cobalt, chromium, vanadium, and mercury may be toxic, studies to date indicate that the significant hazard in mining uranium arises from radon and its decay products. Unless dust-control measures are adequate, miners may develop silicosis, as most of the uranium ores on the Colorado Plateau occur in sedimentary rock containing 30 to 70 percent free silica. Toxic effects also may result from inhalation of uranium dusts.

Radon and Its Decay Products

In uranium mining radon and its two energetic alpha-emitting daughters, radium A and radium C', are considered the most harmful radioactive products. In mine workings radon is emitted from the ore and water seepages and disperses throughout the atmosphere of the mine. The concentration of radon often increases with rock blasting and drilling.

Radium A and radium C' are positively charged radioactive nuclei that adhere to negatively charged dust particles ever present in mine air. These dust particles, to which the radioactive nuclei are attached, and the radon enter the bronchial tubes and lungs through inhalation. While in the lungs radon continues to decay, emitting daughters Ra A, Ra B, Ra C, and Ra C'. In turn, the daughters of radon decay in the lungs discharging alpha particles (besides gamma and beta). Most of the energy of these particles is absorbed by the lung tissues. Dr. W. F. Bale, of the University of Rochester, has estimated that 99.9 percent of the radioactive energy delivered to the lungs comes from the radon daughters.

The harmful effects of overexposure to such radiation may lead to cancer of the lungs.

Experience in European Mines

In European mines, recognizable health damage due to exposure to radon is confined almost entirely to mines in the Ezra Mountains - the Schneeberg mining region of southern Germany and the adjoining Joachimsthal region of Czechoslovakia. Both regions have been mined since the 15th century for silver and other metals. By the end of the 16th century the silver veins were exhausted, and the regions were mined for cobalt, nickel, bismuth, and arsenic. After Madam Curie discovered radium in 1896, pitchblende in these mines was exploited for its radium content.

As early as 1878, reports began to be circulated of a high incidence of lung cancer among miners of the area. According to medical reports, 50 to 70 percent of all deaths in these mines were due to primary cancer of the respiratory system. The cause of these lung cancers has long been controversial and has been attributed to cobalt, nickel, or arsenic. In 1931, Doubrow stated that the cause was still obscure, although the geographic and geologic features of the area and the chemical composition of the minerals were considered. It was suspected that radon might be a hazard to miners, so radon concentrations were measured. Evans and

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Goodman[8/] concluded that the average concentration in these mines was about 1,500 micromicrocuries, which is many times the present recommended standard for safe working conditions. At present the predominant opinion is that radioactivity caused the high incidence of lung cancer. It is possible, however, that no single agent can be blamed but that combined factors of environment are implicated, which are difficult to evaluate.

Experience in American Mines

During the period 1946 to 1949, when uranium production was begun on a large scale in the United States, health officials naturally viewed with alarm the potential health problem associated with mining uranium ores. At the same time it was recognized that the situation in American mines was not comparable to that in European mines and that it was difficult, if not impossible to draw a corollary. American uranium mines are not as deep (although now they are getting deeper - close to 1,000 feet), they yield a rather simple ore compared with the complex ore in the Erz Mountains of Czechoslovakia, and American workers are seldom employed underground over 40 hours a week.

In August 1949 problems that might face this rapidly expanding industry caused Dr. Roy L. Cleere, executive secretary, Colorado Department of Health, to appoint a board to advise both himself and the Colorado State Division of Industrial Health on procedures to be used in conducting studies and surveys in the uranium industry.

Early in 1950, at the request of the Division of Occupational Health, Public Health Service, air samples were taken in uranium mines on the Navajo Reservation by personnel of the Phoenix office of the Federal Bureau of Mines. The radon activity of these samples was determined by the National Bureau of Standards. Radon concentrations were much higher than expected. Subsequent sampling by the Public Health Service verified the original findings.

Preliminary surveys conducted by the Occupational Health Program, Public Health Service, indicated that a potential health hazard existed. As a result of their findings they undertook medical investigations of uranium miners and environmental investigations at the uranium mines. Approximately 700 workers were given medical examinations in the first phase of the study, extending from July to October 1950. During the 1951 season, approximately 460 men were examined; 260 were miners and 200 mill workers. To date, approximately 2,200 miners have been examined (this includes examinations performed in 1950, 1951, 1952, 1954, and 1957). It is believed that this coverage is large enough to permit drawing valid conclusions. As many of the mines and mills were extremely remote, it was necessary to confine the study to the summer and early fall months to avoid bad weather.

The medical study comprised a detailed physical examination, chest X-ray, and clinical examinations of the blood and urine. Analysis of medical histories showed a predominance of respiratory infections, including pneumonia and sinus infection, and conjunctivitis. Specific etiologic or pathologic patterns were not apparent, as most of the workers had been exposed only a few years. Results, however, indicated the need for repeating medical studies frequently.

8/ Evans, R. D., and Goodman, Clark, Determination of the Thoron Content of Air and Its Bearing on Lung Cancer Hazards in Industry: Jour. Ind. Hyg. and Toxicol., vol. 22, 1940, p. 89.

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The environmental phase included determining the nature and concentrations of materials to which the workers were exposed. Through a correlation of these data, it was hoped to obtain information on health hazards associated with the industry so that necessary control procedures could be started. Environmental studies were made in 13 mills and more than 300 mines. These studies comprised evaluating the dust problem, especially the silica content of the dust; determining the nature and extent of exposure to toxic materials such as uranium, vanadium, and other mineral constituents of the ore; and evaluating the radon concentrations in the mines. Analyses of a statistically valid number of samples of mine air for radon and its short-lived daughter products indicated that the concentration of these radioactive substances was too high for safe operation over an extended period, except in places where ventilation was adequate.

In February 1955 a conference in Salt Lake City, Utah, discussed health hazards in uranium mines. Representatives of uranium mine operators and State officials of uranium-producing States met to consider available evidence and to recommend a maximum allowable concentration of radon daughters. The recommendation, based on biological calculations and experiments, was to keep the atmospheric concentration of radon daughters below a potential alpha energy content of 100 micromicrocuries each of Ra A, Ra B, and Ra C' per liter. In other words, radon and its daughter products should not exceed 300 micromicrocuries of alpha-emitting products per liter of air. This recommendation is being followed in most producing States.

This tentative standard should present a factor of safety large enough to prevent damage to the lung tissue of a healthy worker. European experience indicated that long exposure to high concentrations was necessary to produce lung cancer, so the industry is urged to meet this standard. It is far better to be on safe ground in preventing injury to the health of uranium miners than to find later that a reasonable warning was ignored until sad and costly experience proved the extent of the hazard.

Silica

Most uranium ores on the Colorado Plateau occur in sedimentary rock containing 30 to 70 percent free silica. Free-silica dust is considered more dangerous than other dusts in uranium mines and predisposes the miners to silicosis, a disabling condition of the lungs caused by breathing the dust over varying periods. In this disease the normal elastic tissue of the lungs is replaced by inelastic fibrous tissue, which causes shortness of breath, pains in the chest, cough, expectoration, spitting blood, night sweats, loss of strength, and progressive disability. The disease is often complicated by tuberculosis.

The four important factors in causing and/or controlling the occurrence of this disease are: (1) Dust concentrations in the air; (2) size of dust particles; (3) composition of the dust; and (4) length of time the worker is exposed to the dust.

An important statistical study made by the Public Health Service from 1950 to 1954 reveals startling information on the prevalence of silicosis. In 22 States having adequate compensation records, 10,362 cases of silicosis were recorded in the 5-year period; of these, 40 percent occurred in the mining industry and 1,637 cases, or 16 percent in metal mines.

Experience has proved that rigid dust-control measures and adequate ventilation play very important roles in alleviating silicosis in mines.

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Uranium Dusts

The uranium dusts to which miners of the ore might be exposed are uranium dioxide (UO_2), uranium trioxide (UO_3), uranium peroxide (UO_4), and uranium tritaoctoxide (U_3O_8). The toxic effects resulting from inhalation of uranium dusts depend upon the physical characteristics of the dust as well as the chemical nature of uranium. Particle size, density, and solubility are most important because they affect the amount of inhaled uranium retained in the respiratory tract and the rate at which uranium is transported from the respiratory tract to the kidneys, where it has its primary toxic action.9/

Some inhaled dust is deposited on the nasal mucosa; some on the walls of the trachea, bronchi, and bronchioles; some in the alveoli; and some is exhaled into the air. The relative quantities of material retained in the various parts of the respiratory tract depend largely upon the particle size and particle density. Of the retained dust, only that which can be dissolved into the circulation will reach the kidney and result in typical uranium toxicity. The particles of soluble materials deposited either on the nasal mucosa or in the alveoli may be absorbed. Probably the smaller particles of the insoluble dusts, which reach the alveoli, are important.

The results of a recent study on animals conducted by Voegtlin and Hodge showed that:

1. Uranium dioxide was relatively nontoxic when inhaled as a dust in repeated daily exposures. Only at a high level of exposure was toxicity discernible.

2. Uranium trioxide dust was more toxic than expected, owing to its higher solubility in blood plasma than in water.

3. Uranium peroxide is fairly soluble in serum but highly insoluble in water. It is very toxic when inhaled as a dust.

4. Uranium tritaoctoxide, when inhaled as a dust in repeated daily exposures, produced only occasional mild toxic reactions in a 26-day period.

OTHER SAFETY AND HEALTH HAZARDS

The safety and health hazards in uranium mining, besides those already mentioned, are similar to the hazards in other mines in the same areas. Uranium mines vary in size; in the past, any mine employing 10 men was considered large, and few mines employed more than 25 men. Distance and isolation of many uranium mines also pose such problems as lack of water, electric power, and timber.

Many underground uranium mines have been fortunate in having good roofs. Frequently, however, natural pillars needed for roof support were mined out, leaving large openings without adequate roof support. Robbing existing pillars while mining on the advance has often left the same condition. In many instances, mine timbers must be hauled long distances. This fact increases the cost and the difficulty of maintaining an adequate supply. Too often, mining has continued without proper roof support, and dangerous roof conditions have developed.

9/ Voegtlin, Carl, and Hodge, Harold C. (editors), Pharmacology and Toxicology of Uranium Compounds, With a Section on Pharmacology and Toxicology of Fluorine and Hydrogen Fluoride: McGraw-Hill Book Co., Inc., New York, N. Y., 1949, 1048 pp.

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Falls of ground are always a big hazard in underground mines. Uranium miners can benefit from the lesson learned in a recent campaign conducted by the mining section of The National Safety Council. Some 300 mines enrolled in an attack on the problem of injury from falls of ground. The program continued during 1955 and resulted in an average reduction of 29 percent in roof-fall accidents compared with the previous records of the same mines. In addition to the progress made during the campaign, there was a further decrease of 17 percent during the first half of 1956.

The three basic safety measures used to obtain these results are as old as mining itself but are repeated once more. The first measure is to find the loose ground. The second is to take it down, if feasible. The third is to provide adequate support. A good supervisor will insist on this procedure. He knows only too well that many experienced miners have been killed through faulty judgment as to how long a known piece of loose ground would stay in place.

Many uranium deposits could readily use rock bolting for roof support, and more consideration should be given to adoption of this method. As of July 1, 1957, rock bolting was the practice in 181 noncoal mines throughout the United States. The services of Bureau of Mines engineers are available for testing mines and advising management on the possibilities of rock bolting for roof supports.

Large operations generally have safety personnel and active programs aimed at accident prevention. The following example is typical of the safety problems in small operations.

A few years ago a study was made of fatalities in Arizona mines for a 5-year period. The small mines (under 50 men) had 16 percent of the total number of men employed underground, yet suffered 40 percent of the total fatal accidents. Small uranium operations usually lack organized effort in accident prevention owing to one or more of the following factors applicable to many small operations:

1. A fixed rate of compensation insurance with no apparent financial advantage in accident prevention.

2. Limited operating capital.

3. Intermittent operation.

4. Lack of personnel with the time and knowledge to carry out the duties performed by a safety engineer at a large operation.

5. Operations conducted and supervised by persons unfamiliar with mining or with limited mining experience.

6. High labor turnover.

To these conditions are added some often found in uranium mines, such as limited water supply, isolated location, limited timber supply, poor roads, and limited communications. Few uranium mines have trained safety personnel.

A recent review of 196 safety inspections by Federal Bureau of Mines personnel in 83 mines (1954-56), mostly on Indian reservations and public lands, revealed that 47, or 60 percent, of 78 radon-daughter-product samples were above the maximum allowable limit. At 16 mines the workings were ventilated by mechanical means and

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at the remainder only by natural means. Most of the mines were small, employing less than 5 underground workers; 24 mines operated with 2 workers, 13 mines with 3 workers, and 14 mines with 4 workers. The range was 1 to 87 workers.

MEASURES FOR CONTROLLING OCCUPATIONAL HAZARDS

Ventilation for Control of Radioactivity

On the basis of available information, a safe general rule is that adequate protection against internal radiation hazards can be provided by proper ventilation and dust control, in accordance with good mining practice, combined with the personal hygiene measures that have been accepted as necessary in the mining industry. However, in some mines more ventilation is necessary to reduce the radon concentration to the recommended standard than would be required normally to meet good mining practice.

Too many underground uranium mines are operating with inadequate natural ventilation. Proper distribution of air underground demands careful thought and planning, so that clean air will be conveyed as directly as possible to the working places, where it may dilute and remove harmful dust concentrations. Mechanical ventilation should be planned and designed before mining begins and maintained as mining or exploration advances. A split system of ventilation should be used wherever possible. Additional openings not only aid ventilation but provide second exits usually required by State mining laws. With good ventilation the concentration of radon and its daughter products may be held below 300 micromicrocuries per liter of air, and radon may be removed from the mine before extensive decay to its more harmful radioactive daughters occurs. A fundamental misconception carried over from standard mining practice is the delivery to the working face by auxiliary blowers of air picked up in underground workings. The air must be outside air or filtered air from the mine. Radon is released to the mine air throughout the mine workings 24 hours a day, year after year. The concentration in the mine atmosphere when equilibrium is reached ranges from 50 to 100,000 micromicrocuries per liter. As ventilation is essentially a process of diluting the contaminant in the air, the contaminant cannot be diluted with air that has as high or a higher percentage of the contaminant, hence outside air or filtered air must be delivered at the working face of the mine. Although filtration with the proper mediums removes the radioactive nuclei and dust particles, it does not remove the radon. Each mine offers a unique problem and must be considered individually.

In some mines the air is forced to the lower levels and allowed to find its way to the surface through the workings. This should not be done where radon is present. It is necessary to "bleed off" fresh air at frequent intervals so that it may ventilate the immediate workings and then flow from the mine by the shortest route. Once the air is contaminated it cannot be reused without generous dilution. As liberation of radon varies considerably in different mines and in different parts of one mine, the only practicable method of determining whether ventilation is adequate is by determining the concentration of radioactive substances in the mine air. This requires technical training and special equipment.

Sealing off old workings reduces the amount of radon being released to active areas of the mine. To do this, a bulkhead made of 2 by 4's and 1/2-inch plywood is sometimes used. It should be built as airtight as possible by cementing all joints with concrete.

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Auxiliary fans and vent tubing can be used in stopes that are not ventilated by the main air current. Raises, especially the untimbered type, are more difficult to ventilate. Timbered raises usually are not so difficult to ventilate, as vent tubing can be extended as raises are advanced. Experience at Phelps Dodge Corp., Bisbee, Ariz., showed that satisfactory dust control in raises was possible only where tubing was carried 2 feet above the drill platform.

In a Canadian mine, all lateral development places were ventilated with auxiliary fans and vent tubing ranging from 12 to 20 inches in diameter. The best results were obtained at this mine by operating the auxiliary fans blowing rather than exhausting; thus, the crews at the faces were always working in fresh air. Fans were run continuously. The vent tubing was arranged so that it could be pushed back from the face during blasting and still have air blown through it. The amount of air needed to ventilate a heading was about 50 cubic feet of air per minute for every square foot of face.

Theoretical calculations have been made on the rate of ventilation required in uranium mines to control the radon hazard, but the wide differences in observed radon concentrations in mine air make it difficult to arrive at definite conclusions or to recommend minimum ventilation rates. Natural ventilation is considered inadequate in most mines. On the basis of maximum observed rates of radon emanation, 15 air changes per hour have been suggested. Mine operators feel that such a value is impracticable and economically prohibitive. It has been stated that the hazard from radon would be suitably controlled in many uranium mines if ventilation was provided at the rate now required underground to provide safe conditions after blasting and when diesel equipment is used. Each mine, however, should have its particular problems evaluated so that enough ventilation will be provided to maintain minimum hazards from radioactivity.

Specifications for mine ventilation based upon a certain quantity of air per man will not be applicable to uranium mines. Every mine presents a different ventilation problem, and controls must be designed for the specific conditions. To offset the radioactivity hazard, ventilating requirements of uranium mines usually should exceed those of ordinary mine operations and should have little relation to the number of men underground.

Ventilation for Control of Dusts

Customary dust-control practices should be emphasized, because the dust is contaminated with radioactive materials. These include wet drilling, the generous use of water on muck piles during loading, and the wetting down of working places. Mine water, however, should not be used, unless it is known to be free from radioactive contamination; however, the remote location of many uranium mines makes use of copious amounts of water difficult. Adequate dust control is even more important in uranium mines than in other mines where the problem is only to suppress siliceous dusts. Dust concentrations in uranium mines have greater physiological significance, as any dust breathed into the lungs is contaminated with radioactive material.

It is the responsibility of supervision to educate miners concerning the reasons for wet drilling and to see that such safe practice is followed consistently.

The single-shift operations of many small mines are beneficial in allowing an overnight period for settling the dust and clearing the mine atmosphere. In such mines blasting should be done only at the end of the shift.

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Other Safety and Health Recommendations

Fortunately, small operations can accomplish results in accident prevention corresponding to those at large operations with a complex program. Two ingredients are essential at both large and small mines - competent supervision and a sincere belief in safety and safety education of employees.

A competent supervisor is difficult to obtain where pay is low, future operations uncertain, and living conditions poor. Nevertheless, a competent supervisor who believes in accident prevention is essential for safe, efficient operation. The money spent to retain such an individual is an intelligent investment.

Safety education should instill a desire to work safely in the minds of the employees and teach them how to work safely. Competent supervision will then require that the work be done in a safe manner.

Employees may be educated in safety at little expense. Their immediate supervisors, through day-to-day contacts, have an excellent opportunity to instruct employees in safe working methods. Setting a good example is still a good method of teaching a new man, whether the good example is set by the supervisor or an experienced fellow worker.

First-aid training is a good way to begin safety instructions. A course in first-aid training will show employees the consequences of an unsafe act, and frequently will produce immediate improvement in the accident rate. First-aid training has an additional advantage of teaching employees to care for their injured fellow workers. This training is doubly valuable in isolated locations. The Bureau of Mines also offers a metal-mine accident-prevention course that treats more specifically with the hazards and problems of a particular property. Both courses are available through the Federal Bureau of Mines.

Inexperienced miners have been found working in isolated mines or remote parts of mines with little or no supervision. Even experienced miners need day-to-day supervision and discussions with an experienced supervisor to maintain safe working habits and make efficient progress. Inexperienced men have even greater need of guidance and adequate training if they are to develop into safety-conscious employees.

Much makeshift equipment has been observed in uranium mines, sometimes because it is difficult to repair or replace equipment owing to the isolation of the mine and sometimes because expenditures for equipment must be kept at a minimum. Certainly, where human life is at stake, expenditures should be adequate to afford safe working conditions. Following expediency in repairing or replacing equipment too often has caused needless injuries, resulting in a high frequency and severity of accidental injuries.

General carelessness in storing and handling explosives also has been noted. In isolated places, realization of the need for safe storage is probably dulled, but accidents from explosives have injured people not directly connected with the mining operation, even in the far reaches of the Navajo Reservation. Safe storage should always be provided for explosives.

Both carelessness and inexperience have caused explosives accidents in uranium mines. Miners must be instructed in the safe use of explosives and given enough supervision to see that these safe methods are followed.

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As there are potentially dangerous gaps in our knowledge of the effects on health of a combination of hazards in uranium mines, all recommended measures should be strictly followed, including the use of respiratory protective equipment, personal cleanliness, proper nutrition, periodic physical examinations, and chest X-rays.

FIELD METHOD FOR SAMPLING AND DETERMINING CONCENTRATIONS OF RADON DAUGHTER PRODUCTS

Relatively simple and inexpensive equipment has now been designed and tested in the field for sampling and determining atmospheric concentrations of radon daughters. Filter paper, a filter holder, a small hand-cranked or battery-operated pump, and a calibrated alpha survey meter are the only equipment needed. The method follows:

1. Draw a known quantity of mine atmosphere (14 to 23 liters per minute) through a hand-cranked vacuum pump or other suitable air-moving device for either a 5- or 10-minute period. The sampling head, affixed to the pump, holds an aerosol molecular-type filter paper upon which the radon daughter product particles are deposited. As the pump is previously calibrated for a standard rate of operation, the time required to draw the sample will indicate how many liters of air has passed through the filter paper. When the plunger-type pump is used, each stroke represents the intake of 1 liter of air.

2. Remove the filter paper for each sample from the mine, after placing each in a glassine envelope for protection until the radiation on the filter paper is measured.

3. Take an alpha survey meter reading of the filter activity from 40 to 90 minutes after end of sampling. Convert the alpha survey meter reading to disintegrations per minute (dpm).

4. Divide this reading by the number of liters sampled to give dpm per liter.

5. Divide the dpm per liter by the factor on the graph shown in figure 1.

6. The resulting figure gives the multiple or fraction of the suggested working level (1.3×10^5 Mev/l) existing in the air. Multiply this figure by 1.3×10^5 to determine the amount of potential alpha energy in million electron volts of energy per liter of air.

Details of the sampling method are described in a recent article.10/

Advice regarding the purchase of equipment may be obtained from the Field Station, Occupational Health Program, United States Public Health Service, Box 2537, Fort Douglas, Salt Lake City, Utah.

10/ Kusnetz, H. L., Radon Daughters in Mine Atmospheres - A Field Method of Determining Concentrations: Am. Ind. Hyg. Assoc. Quart., vol. 17, March 1956, pp. 85-88.

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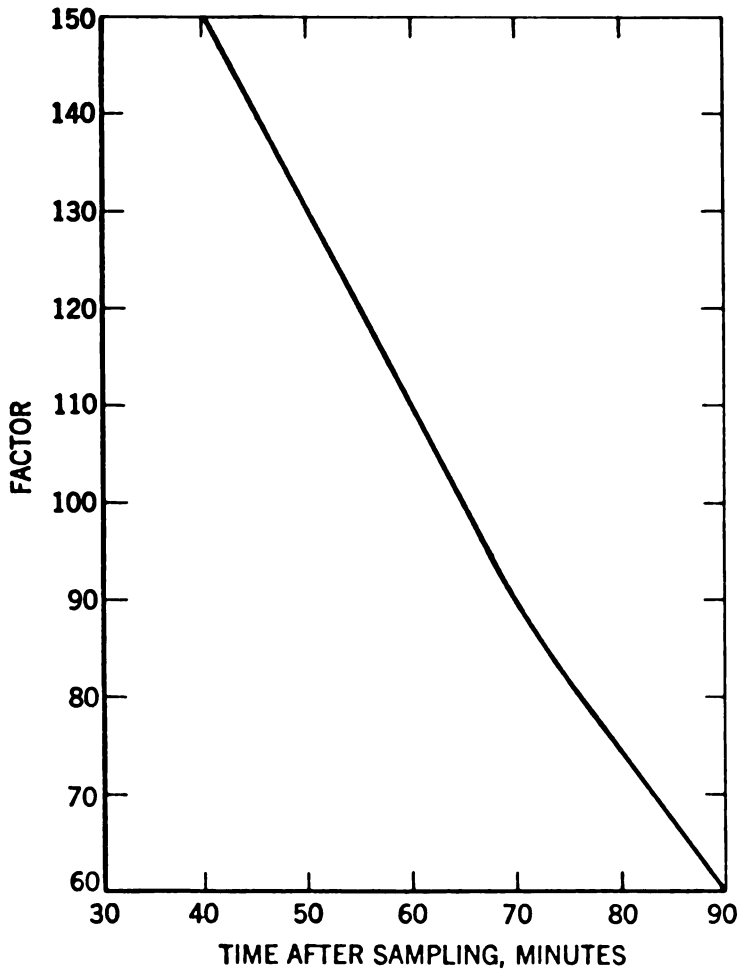

Figure 1. - Factors for determining percentage of tolerance level of radon daughter products in the atmosphere.
Tolerance level: 1.3×10^5 mev./liter.
(Mev: Million electron volts of energy).

FEDERAL BUREAU OF MINES RESPONSIBILITY

At present the Federal Bureau of Mines has clear responsibility under Order 1940, issued by the Secretary of the Interior, for all mine safety inspections in mining operations on the Public Domain, Indian lands, and other Government-leased lands. In an opinion dated May 18, 1956, however, the associate solicitor of the Department of Interior concluded that the Federal Bureau of Mines has no authority to make safety inspections of uranium mines located on the Public Domain, where the lessee obtained his lease from the Atomic Energy Commission or where, instead of a lease, the operator or owner has filed a mineral claim. The Bureau of Mines has no authority to inspect uranium mines on privately owned land.

STATE REGULATORY MEASURES

Mining laws are formulated by the Governments of the States to protect both employees and mine operators. In the interest of mine safety, it is strongly recommended that everyone concerned with mining should familiarize themselves with the State laws and comply with them. Excerpts from regulations of the three major uranium producing States - New Mexico, Utah, and Colorado - are quoted as follows:

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New Mexico Mine Safety Code for All Mines Including Open-cut and Open-pit, 1955, Article 26, Ventilation and Gases in Mine Other Than Coal, 63-26-1.

(b) In any underground uranium mine producing radioactive ores in which radon gas is present, the operator shall provide on the surface or underground, a fan or other mechanical device for producing and controlling air circulation within the mine capable of delivering fresh air at the rate of five hundred cubic feet per minute for each man or at a higher rate where it is necessary to reduce to acceptable levels the danger from radon gas encountered where men are working. For this purpose the Mine Inspector may, in his discretion, prescribe the rate or rates for the delivery of fresh air by mechanical means for any such mine or any particular workings therein.

Passed by the Industrial Commission of Utah, Salt Lake City, Utah, August 25, 1955.

IT IS ORDERED: That the General Safety Orders issued by The Industrial Commission of Utah, effective July 1, 1945, are amended by adding the following regulations:

1. The operator of every uranium mine, whether operated by shaft, slope, tunnel, adit or drift, shall provide and maintain for every such mine a good and sufficient amount of ventilation for such men and animals as may be employed therein, and shall cause an adequate quantity of pure air to circulate through and into all shafts, winzes, levels and all working places of such mine, and except in case of an emergency, no man shall be allowed to work in an atmosphere injurious to health.

2. The atmospheric concentration of the immediate daughters of radon should not exceed 300 MMCL as determined by a field method acceptable to the State Bureau of Mines (Industrial Commission) and every operator shall make a reasonable effort to approximate said standard.

3. Rule on Determination of Concentration of the Immediate Daughters of Radon.

   It shall be the duty of every operator to cause an inspection of the mine to be made each month for the purpose of determining the concentration of the immediate daughters of radon, provided, however, that at the discretion of the Mine Superintendent or the State Mine Inspector more frequent determinations may be made, and all such determinations shall be made at the working place.

   Recording of Determinations

   It shall be the duty of the operator to maintain a record book at the mine office wherein the individual making the inspection and determination shall record his findings in his own handwriting and over his own signature, setting forth specifically the time and the places of inspection and determination, and such information (record book) shall be available to the Mine Inspector on request.

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This Order shall take effect as of January 1, 1956.

THE INDUSTRIAL COMMISSION OF UTAH

Colorado Mining Laws With Rules and Regulations:
Bulletin 16, June 30, 1954, pp. 152-153.

Radon

In places containing radon gas and its decay products the maximum allowable concentration for the alpha emitting decay products of radon should not exceed one hundred (100) micro-microcuries per liter of air.

4. The maximum allowable concentration of toxic dusts, mineral dusts, and fumes shall be according to the standards in Regulation Three (3) on Occupational Hazards, as set forth by the Colorado State Department of Public Health.

5. When employees are exposed for only short periods of time to dust or fume hazards, they shall wear approved respiratory equipment, but when the exposure is for prolonged periods, other means to protect the employees or to reduce such hazards must be taken.

6. Drill holes underground shall not be collared dry, but drilling water shall be turned on before the air drill is put in operation, or other means used to control dust.

7. All chutes from which dusty ore or rock is taken shall be equipped with a sprinkler or other such device which will effectively dampen such rock or ore, which will prevent the escape of dust in the atmosphere.

8. Wherever the sprinkling device is installed in a chute for the purpose of preventing the escape of dust, it shall be so placed that it can be operated by the employees loading cars at the chute.

9. Wherever it is necessary for an employee to use a respirator in the performance of his duty, such respirator must be furnished by the employer.

10. Respirators shall be of an approved type, kept clean and sanitary, and the employee must wear them where needed.

11. Before starting mucking or shoveling in any working place, the working place, and ore or rock piles, shall be sprinkled before starting work, and kept sprinkled as often as necessary so that no dust will arise from such pile of ore or rock.

12. In underground workings where dusty waste is being used for back filling, it shall be kept damp so that it cannot contaminate any air course with dust.

13. District mine inspectors will, as frequently as necessary, determine whether any hazardous dust conditions exist in mills, excavations, mines or quarries, and if such hazardous conditions do exist, will recommend to the employer methods of reducing or eliminating the dust or fumes to prevent such hazardous conditions.

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CONCLUSIONS

The Federal Bureau of Mines has no authority to enter a noncoal mine without the consent of the operator, unless the mine is on Government-owned or Government-controlled property. The Bureau's work is largely educational; safety inspections and dust, ventilation, and gas surveys usually are made at the request of a mine operator or other interested persons. Suggestions for correcting any hazards that are noted by the inspector are made in the form of recommendations only and do not have the force of law.

Uranium mining can be made safe, and it is believed that the following actions should achieve this end:

1. Adequate mechanical ventilation should be provided so that the radiation level at any working place does not exceed 300 micromicrocuries of total radon daughters per liter of air and the atmosphere is kept free from harmful quantities of gases and dusts.

2. Stringent dust-control measures for preventing or allaying harmful quantities of airborne dusts should include wet drilling, the generous use of water on muck piles during loading, and the wetting down of working places. In mines where trackless loading and haulage equipment stir up much dust, good results can be attained by applying calcium chloride to the mine floor.

3. Adequate support should be provided for loose ground.

4. Surface fire protection commensurate with the value of the buildings and their contents should be provided, and water for fire protection should be available throughout the mine.

5. Safeguards should be provided for mechanical equipment, and all equipment should be maintained in good repair.

6. Explosives should be stored and handled properly.

7. All concerned should be familiar with State regulations and should adhere to them.

8. All employees should be trained until competent to do their work in a safe manner, and only competent safety-minded supervisors should be employed.

9. Goggles, protective clothing, and Bureau of Mines approved respirators should be available and used when needed.

10. First-aid training and first-aid material should be provided, as well as a continuing safety program.

11. Good personal hygiene should be practiced by all workers. Daily baths and frequent change of work clothes are recommended. Eating and storing food in the mine should not be permitted.

12. All new employees should be given thorough physical examinations (including laboratory analyses of blood and urine and chest X-rays). Previous occupational and medical histories should be obtained. Follow-up medical examinations should be made annually.

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13. Everyone engaged in uranium mining from top management down to miners should have a general knowledge of the radiation hazard and should know how to protect their fellow workers and themselves.

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